

**IMPLEMENTATION OF PHYTOREMEDIATION
AT THE WAUKEGAN MANUFACTURED
GAS AND COKE PLANT SITE,
WAUKEGAN, ILLINOIS**

Report Prepared by:

**John S. Fletcher
Professor of Botany
Dept. of Botany and Microbiology
University of Oklahoma**

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TABLE OF CONTENTS

INTRODUCTION	3
BACKGROUND PRINCIPLES OF PHYTOREMEDIATION TECHNOLOGY	5
Prevention Of Soil Erosion/Plant Cover	5
Restriction Of Contaminant Leaching Through Plant Evapotranspiration	5
Promotion of PAH Degradation	11
Sustained, Longterm, Economical Phytoremediation/Ecological Considerations	16
ASSESSMENT OF THE WCP-SITE FOR PHYTOREMEDIATION	19
Plant Growth Conditions	19
Topography	19
Available Water	19
Temperature	20
Soil	22
Vegetation Currently Growing At The WCP-Site	23
PHYTOREMEDIATION OF THE VADOSE ZONE AT THE WCP-SITE	25
Method	25
Rational For Using Selected Plants	27
Anticipated Results	27
REFERENCES	29
FIGURES	
Figure 1. Mechanism of plant evapotranspiration showing controlling environmental factors	6
Figure 2. Relationship between plant leaf-biomass and water lost through evapotranspiration	8
Figure 3. The shoot height and root depth of eight different grass species including two tallgrass prairie species, big bluestem and switchgrass	9
Figure 4. Photograph showing the extensive root system of bluestem and switchgrass	10
Figure 5. Fate of organic chemicals subjected to phytoremediation	12
Figure 6. Plant potential	14
Figure 7. Annual influence of root turnover on microbial-substrate release and oxygen diffusion	15
Figure 8. Root zone beneath a 12 year-old mulberry tree growing in a former chemical sludge basin	17
Figure 9. Distribution of major grassland types in the United States	26
TABLES	
Table 1. Total PAH concentrations (ppm) from corings within the mulberry root zone (0-110 cm deep) and non-rooted sludge	18
Table 2. Monthly summary of the accretion, depletion, and storage of soil water as determined by the weighing lysimeter Y101D at the U.S. Department of Agriculture Experimental Station located near Coshocton, Ohio	21

INTRODUCTION

Bioremediation efforts during the last 20 years have relied almost exclusively on the use of microorganisms (1,2) with little thought or effort given to capitalizing on the favorable properties afforded by terrestrial plants for the economical reclamation and restoration of contaminated soil. The standard practice in the past has been to remediate a contaminated site through various means, and then introduce plants at the end during site closure. Plants have been used to arrest the erosion of surface soil placed over clay caps designed to reduce water infiltration and leaching of residual contaminants. This is a very limited use of plants in view of the fact that in natural, healthy ecosystems plants play a major role in the recycling of both water and nutrients. A more appropriate use of plants is to introduce plant species early in the remediation process to prevent contaminant leaching by removing excess water and to foster the continuous degradation of soil organics, including industrial contaminants. This broadened use of plants is patterned after their performance in natural ecosystems. Expanded use of plants in remediation of contaminated soils has been termed phytoremediation (3,4). Since plants are the primary producers of organic food sources for microorganisms, animals, and all other life forms, it follows that successful introduction of phytoremediation technology has ecological overtones. Plants operating in unison with soil bacteria and fungi provide a natural means to convert contaminated sites (ie. the WCP-site) into restored ecosystems.

The remediation of the WCP-site in Waukegan, Illinois is ideally suited for implementation of phytoremediation technology. Plants and associated microorganisms introduced and maintained at this site can be used to accomplish 3 different objectives:

- 1) prevent soil erosion.
- 2) restrict contaminant leaching by removing soil water.
- 3) promote degradation of PAHs and other organic contaminants.

The success of phytoremediation at the WCP-site is strongly dependent on the proper selection of plants. The plants should be ecologically adapted to grow under the climate and chemical conditions at the site, and they should also be structurally and physiologically suited to remediate and restore the distressed soil ecosystem present at the WCP-site.

BACKGROUND PRINCIPLES OF PHYTOREMEDIATION TECHNOLOGY

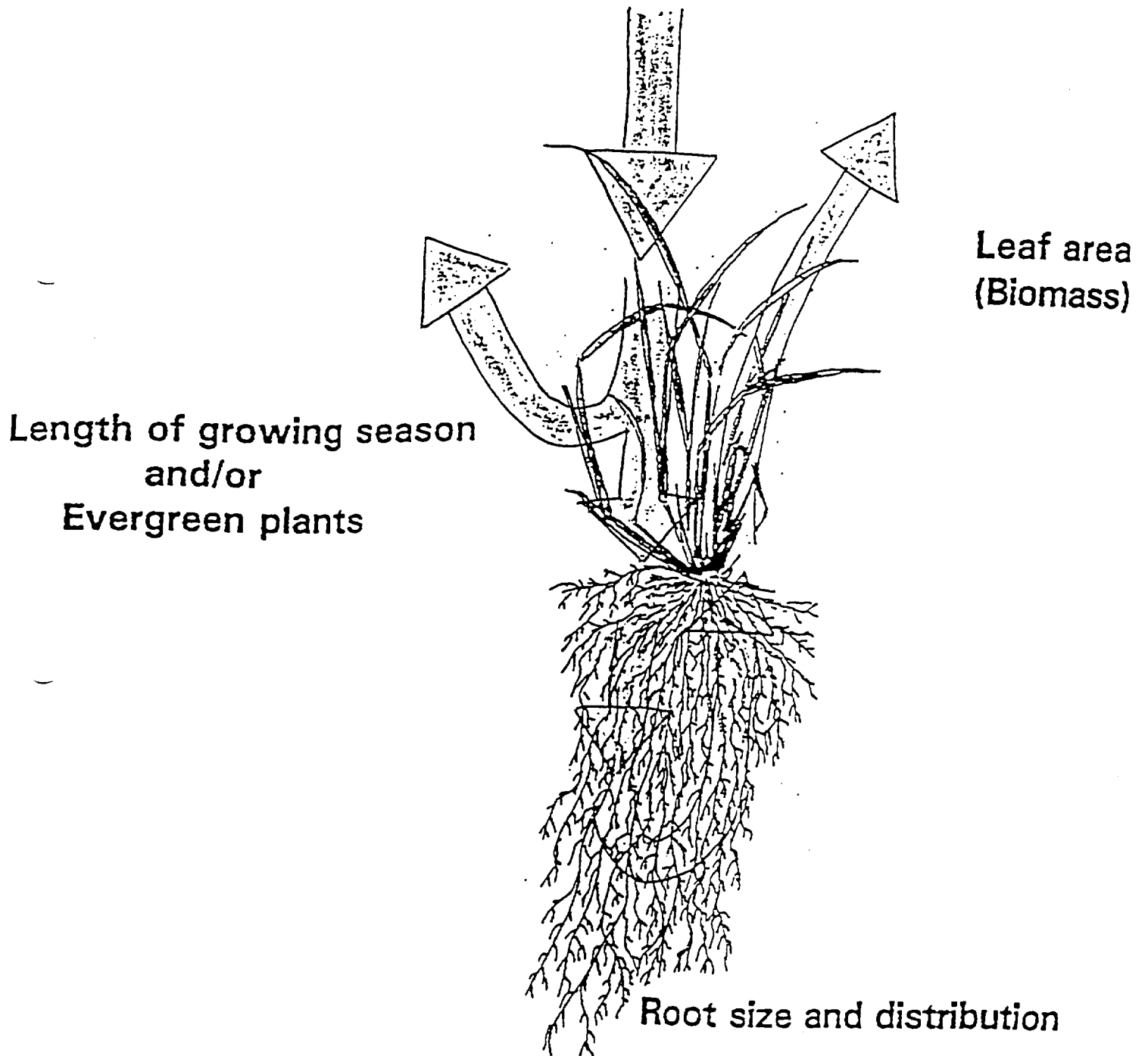
Prevention Of Soil Erosion/Plant Cover

Vegetative cover, both living and dead, is instrumental in preventing soil erosion. Initially this is brought about by reducing the physical force of raindrops that loosen soil particles when they strike bare soil, allowing suspended soil particles to be carried off in runoff water. Another important feature of plants is that beneath the dead plant litter, characteristic of dense plant communities, the surface and upper strata of soil are porous and thereby prevent rain water from collecting on the surface and running off as an erosive force. The interwoven network of roots in the upper layers of soil are also important in holding soil in place in the event that erosion does start. The plant features that prevent soil erosion are common to all plants and therefore almost any plant species is satisfactory for this purpose providing it grows fast and forms a dense cover, thereby eliminating bare soil that is subject to soil erosion during rainstorms.

Restriction Of Contaminant Leaching Through Plant Evapotranspiration

Plants have a profound influence on the recycling of rainwater from the soil to the atmosphere through the plant-mediated process of evapotranspiration. Efficient return of rain water to the atmosphere prevents its downward migration in the soil and thereby eliminates the prospect of it causing soluble contaminants to be leached to lower soil depths and/or groundwater.

Figure 1. Mechanism of plant evapotranspiration showing controlling environmental factors.

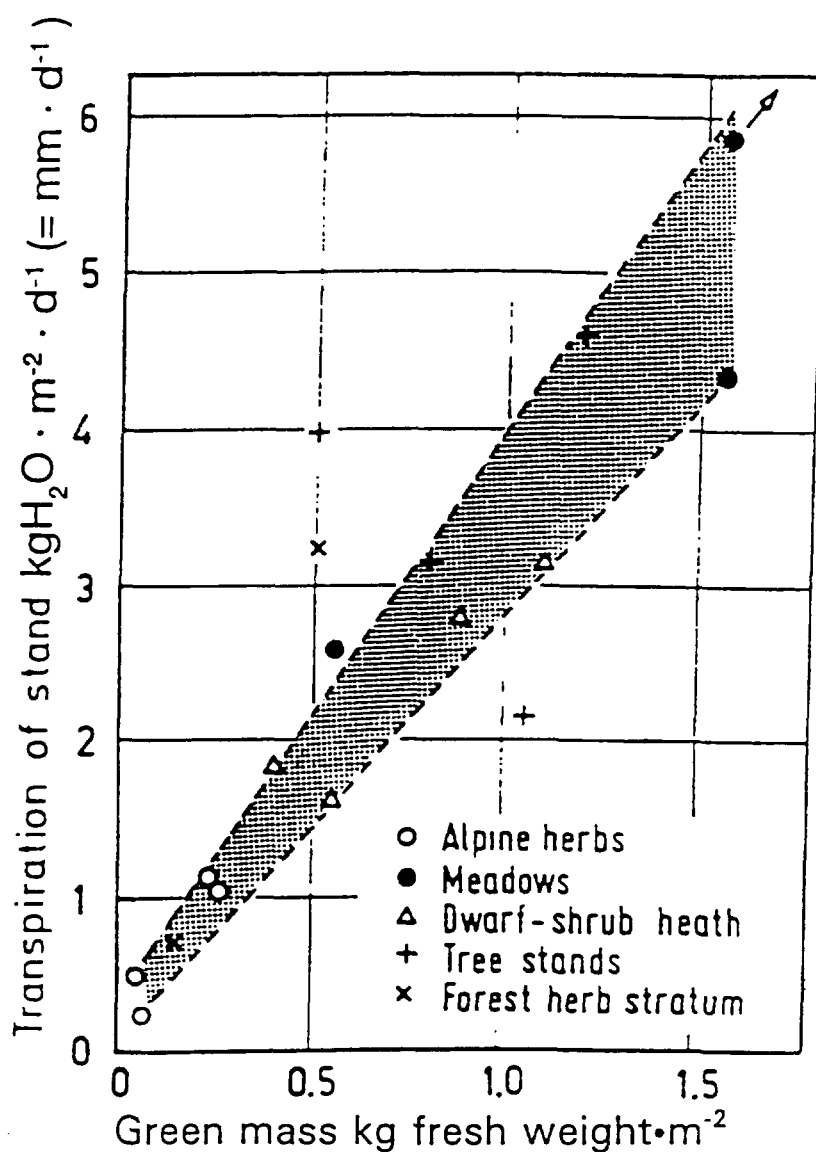


The evapotranspiration process is a result of two events, both of which are dependent on the magnitude of leaf surface area (Figure 1). First, plant leaves intercept falling rain, and a portion of it remains suspended on the leaf surfaces until it evaporates back into the atmosphere. As a result, light rains falling on dense leaf canopies never reach the soil surface. During periods of heavy rain when leaf surfaces become saturated, the excess water drips to the ground and soaks into the porous surface soil where it is subject to uptake by plant roots and subsequent return to the atmosphere through plant transpiration. During plant transpiration large amounts of water absorbed by roots are transported up the stem to leaves where the water evaporates back into the atmosphere. The amount of water lost from an individual plant or stand of vegetation is directly dependent on the magnitude of leaf surface area, conveniently measured and expressed as biomass of green tissues (Figure 2). Two other factors that influence transpiration are the length of the growing season (or retention of leaves during winter), and the distribution of the root system (Figure 1).

Deep-rooted, tall grasses such as those species native to the tallgrass prairie (ie. switchgrass and bluestem) are ideally suited for enhanced evapotranspiration, because of their deep, extensive root systems (Figure 3) coupled with large aboveground leaf biomasses. These species possess 80% of their total biomass as roots, which are genetically capable of reaching depths of 10 feet (Figure 4).

Thus, the ideal plant species to enhance the removal of water from the soil is a plant with: 1) a large leaf surface, 2) ability to retain leaves over a large portion of the year, and 3) a large, deep, spreading root system. All plant species are not equally endowed with these characteristics, but there are numerous plant species, including both grasses and trees (Figure 2), that are well suited for accomplishing this phytoremediation objective.

Figure 2. Relationship between plant leaf-biomass and water lost through evapotranspiration.



Taken from reference 5.

Figure 3. The shoot height and root depth of eight different grass species including two tallgrass prairie species big bluestem and switchgrass.

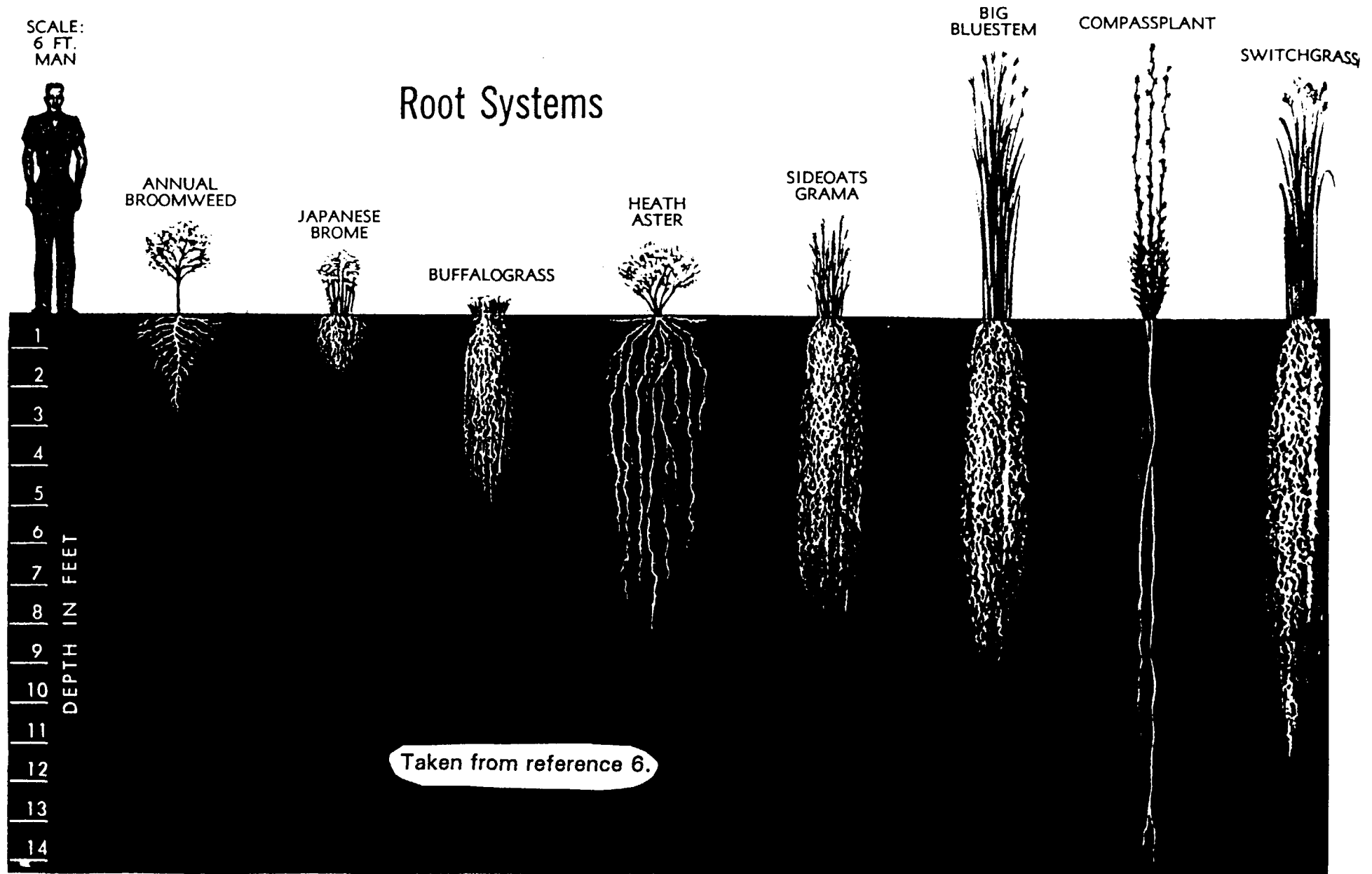


Figure 4. Photograph showing the extensive root system of bluestem and switchgrass.

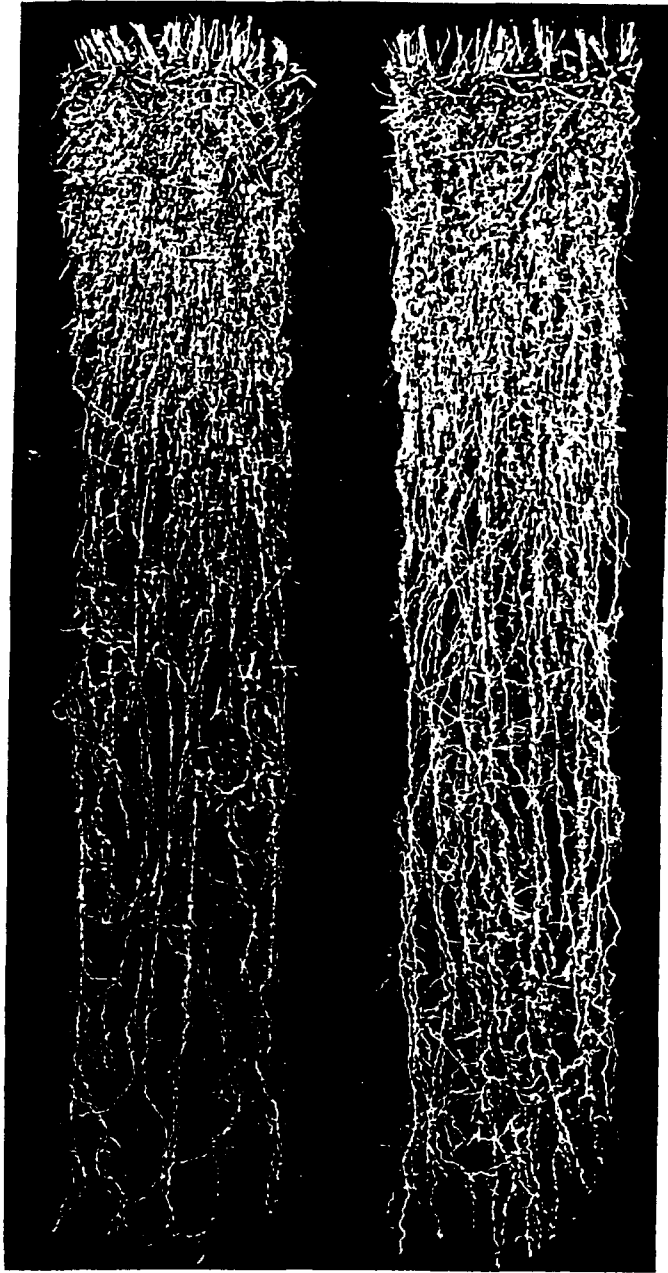


FIG. 5.—Roots of big bluestem (*Andropogon gerardi* [left]) and switchgrass (*Panicum virgatum*) from monoliths of soil 12 inches wide, 3 inches thick (into the trench wall), and 5 feet deep. The bluestem was 7 feet and the switchgrass more than 8 feet deep. From Weaver and Darland, *Ecological Monographs*, 1949a.

Taken from reference 7.

Promotion Of PAH Degradation

The influence of terrestrial plants on the fate of organic soil pollutants is primarily dependent on two factors, the physical/chemical properties of the pollutant and the physiology of individual plant species (Figure 5). Contaminants that have a high water solubility and low $\log K_{ow}$ (ie. BTEX compounds) will be prone to be taken up by plants, transported in the translocation stream, and metabolized in various tissues through which the contaminant passes during movement from root to leaf (8). If the contaminant is both water soluble and volatile, it will be wicked through the plant and into the atmosphere, but only if its concentration in the soil is high (9).

Contaminants with low water solubility and high $\log K_{ows}$ (ie. PAHs) tend to be immobile in the soil, not toxic to plant growth (10), and also not readily reacted upon by the plant's catabolic enzymes (11). Therefore, the biological degradation in the soil of compounds such as the PAHs appears to be primarily a feature of microbial metabolism. However, plants are important in this process, because the roots of some plant species selectively stimulate microorganisms in the soil that are capable of degrading PAHs (12).

A major contributing factor to the persistence of recalcitrant contaminants is that only a few microorganisms appear capable of degrading these compounds. Thus the challenge in bioremediation of such compounds is to promote the growth and activity of the small, minority component of the indigenous microbial community that can degrade the contaminant and at the same time suppress the growth of the general microflora, thereby changing the composition of the microbial community in favor of the organisms that can degrade the recalcitrant compounds. Laboratory studies (13,14) and some field work (15) have shown that a successful strategy to accomplish this goal is to provide cometabolites that selectively

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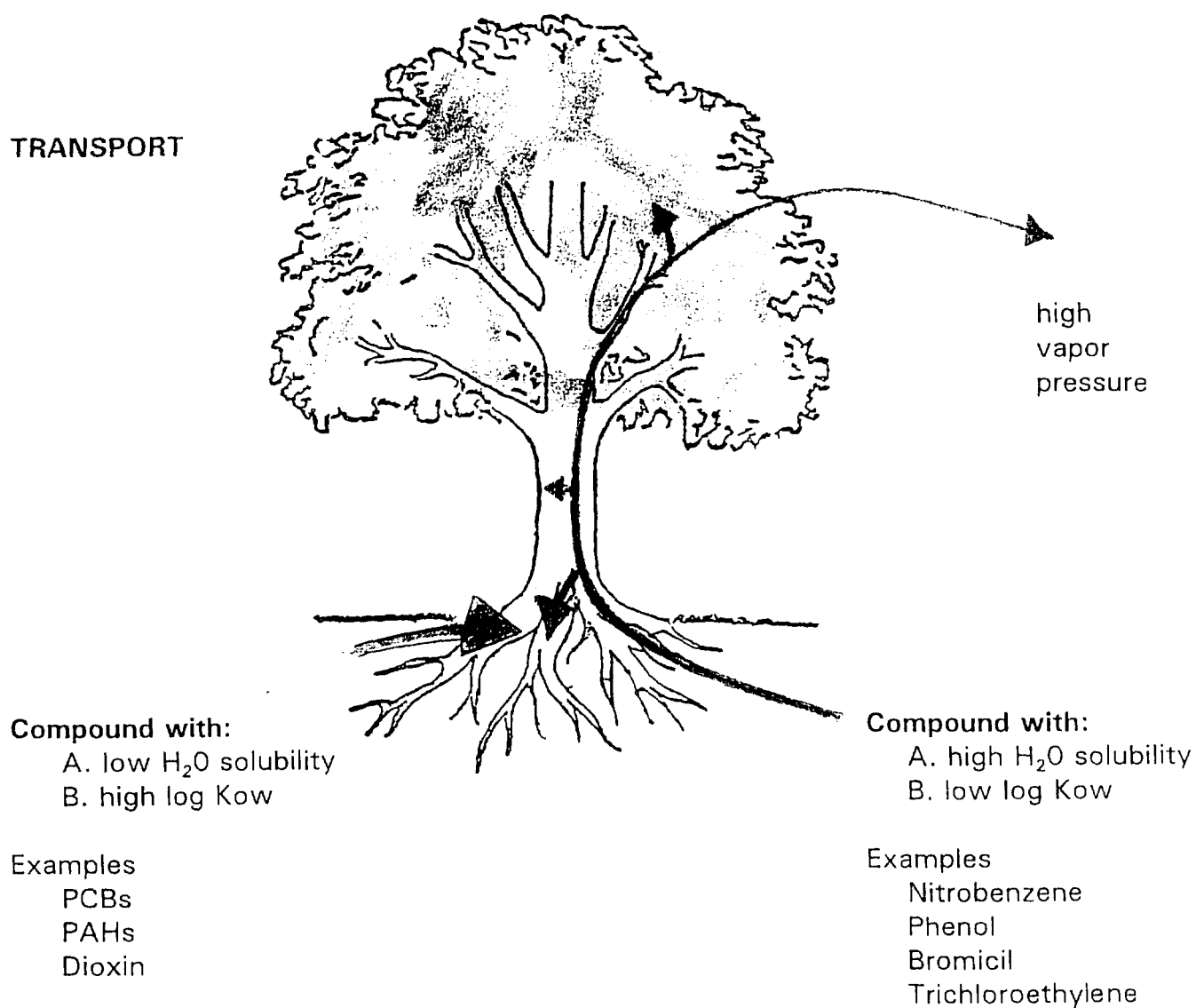
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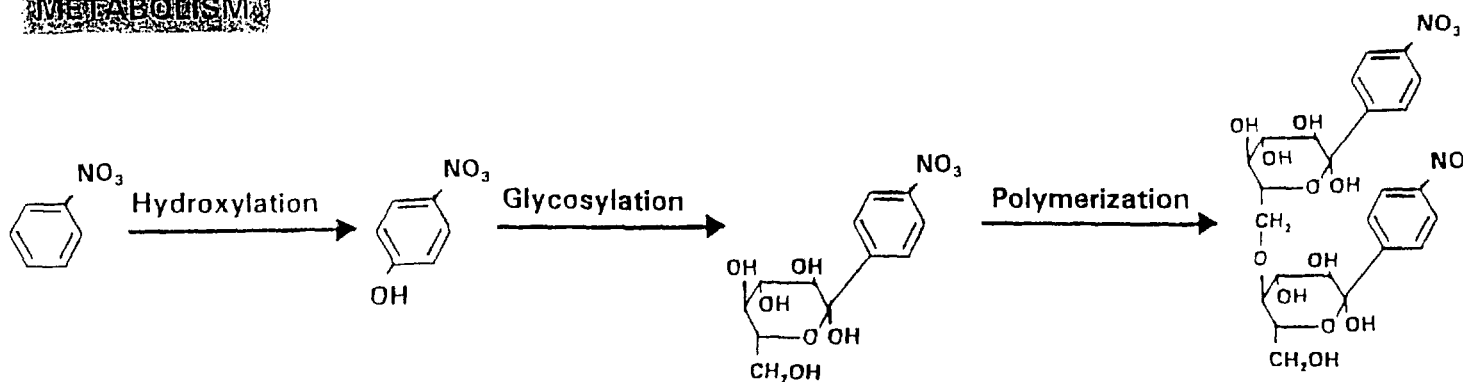
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Figure 5. Fate of organic chemicals subjected to phytoremediation.



METABOLISM



foster the growth and activity of desired organisms. Furthermore, it has been shown in our laboratory at the University of Oklahoma (16,17) that some plant compounds such as flavonoids and coumarins serve as natural substrates for the growth and enhanced activity of bacteria capable of degrading recalcitrant compounds. All plant species do not synthesize and release the same kinds and amounts of chemicals into the soil (19). Therefore, research has been necessary to identify plant species whose roots produce and release large amounts of compounds that structurally resemble industrial contaminants (Figure 6). Several plants such as: mulberry (18), osage orange (18), hackberry/sugarberry (20), and sweet clover (21) have been shown to produce such compounds, and other plants such as little bluestem, big bluestem, indiagrass, and switchgrass have been shown to foster PAH degradation (22,23,24). Therefore these plant species are excellent candidates for use in sustained phytoremediation of residual amounts of industrial polyaromatic contaminants, providing they will grow under climate conditions prevailing at a site.

Growing selected perennial plants (ie. those identified in the previous paragraph) in PAH-contaminated soil provides continuous sustained remediation of the soil. This is brought about by the stimulator influence that fine root turnover (continuous death and regrowth) has on the proliferation and activity of PAH-degrading bacteria. The dynamic turnover process of fine roots releases microbial substrates and opens passage ways for oxygen diffusion through root traces left by dead roots. Thus, the root of a perennial plant functions as an injector system for both microbial substrates and oxygen (Figure 7).

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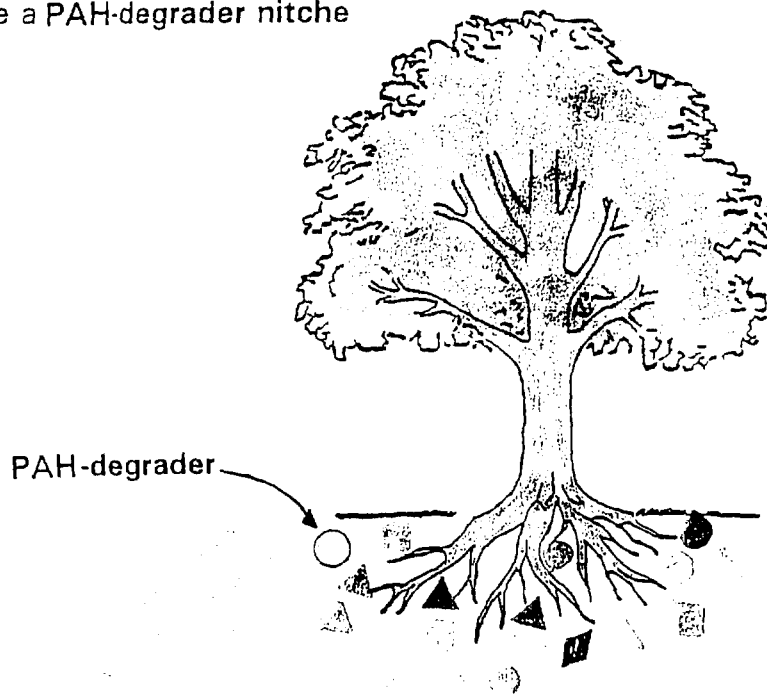
FACTS

1. One gram of soil contains 10,000 different kinds (species) of bacteria.
2. A few kinds of bacteria are capable of degrading PAHs

CHALLENGE

Promote the growth and activity of PAH-degrading bacteria over that of the other competing 10,000 organisms.

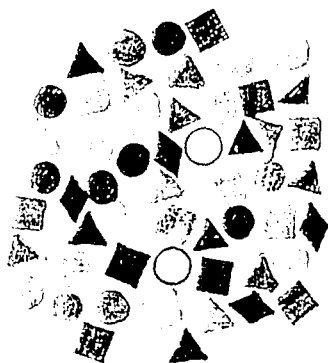
Create a PAH-degrader niche



All plants
Produce

Amino-acids
Sugars
Organic acids

All 10,000 bacteria
grow

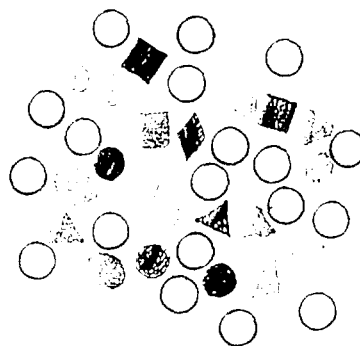


NO PAH-degrader niche

Some Plants
Produce

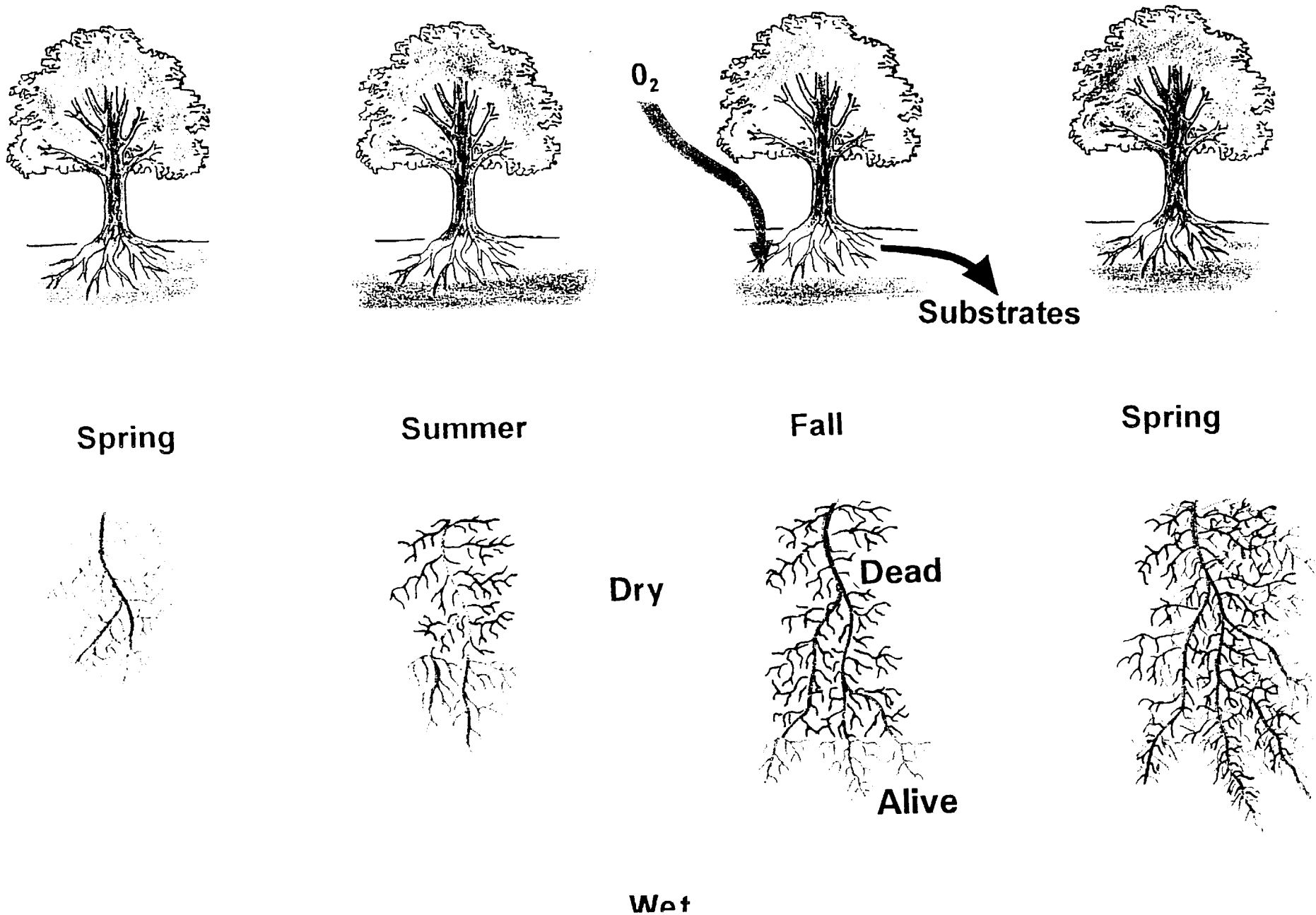
Biphenyl Substitutes
Flavonoids
Coumarins

Some bacteria grow



PAH-degrader niche

Figure 7. Annual influence of root turnover on microbial-substrate release and oxygen diffusion.



Evidence that certain plants can enhance PAH degradation under field conditions has been provided by analysis of soil/sludge samples collected from a naturally revegetated sludge basin in Texas City, Texas. Quantification of PAHs present in the root zone of a 12 year-old mulberry tree growing at this site (Figure 8) has shown a strong correlation between the presence of roots and the disappearance of PAHs (Table 1). The disappearance is attributed to the over 200 bacterial isolates recovered from the root zone of mulberry growing at the site. All of the isolates are capable of growing on naphthalene, phenanthrene, or pyrene as a sole carbon source.

Sustained, Longterm, Economical Phytoremediation/Ecological Considerations

To achieve sustained, longterm, economical phytoremediation it is imperative that a contaminated site be planted with perennial vegetation that is adapted to the environmental conditions prevailing at the site and that the specific plants selected be robust, aggressive plants that will not be immediately replaced by more competitive wild species prone to invade the site. To avoid the latter the best strategy is to capitalize, whenever possible, on plant species that are a part of the natural vegetation currently growing on and adjacent to the site or that are known from ecological publications to be natural components of plant communities and ecosystems characteristic of the region.

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Figure 8. Root zone beneath a 12 year-old mulberry tree growing in a former chemical sludge basin.

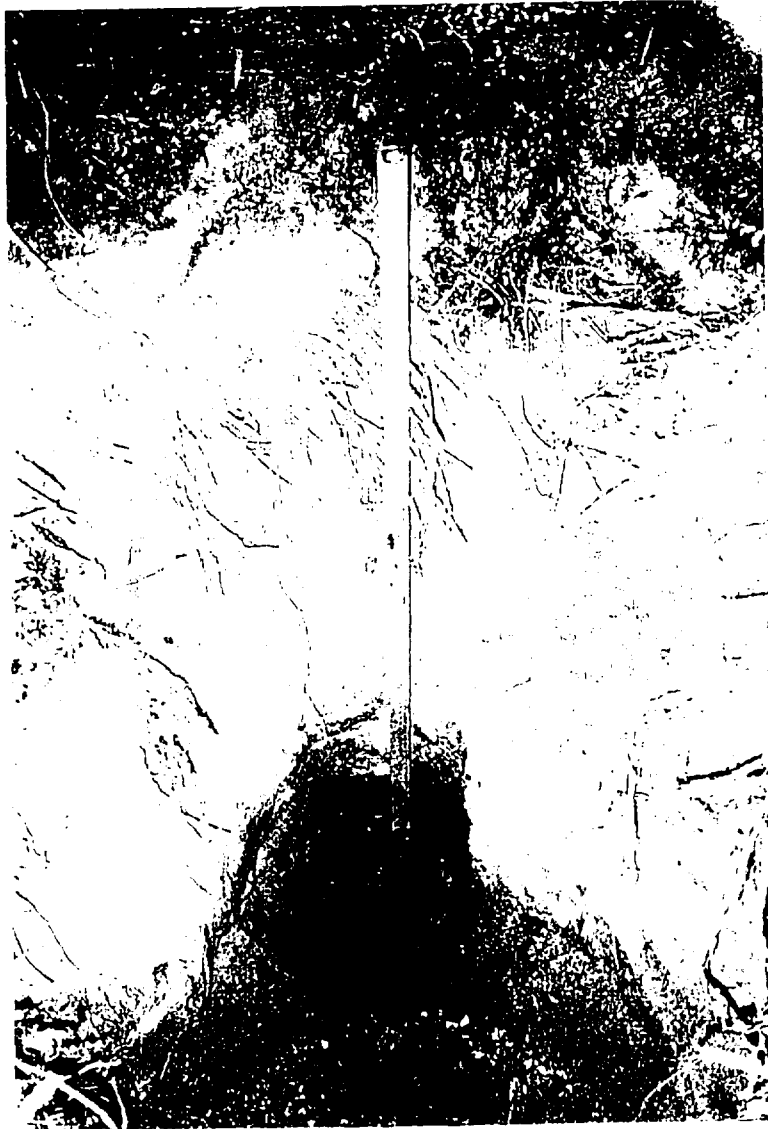


Table 1. Total PAH concentrations (ppm) from corings within the mulberry root zone (0-110 cm deep) and the non-rooted sludge.

Segment/Zone of Core	Coring distance (m) from base of mulberry trunk		
	0 m	1.5 m	3 m
First Segment (0-30cm)	2810.4	1266.3	632.4
Second segment (30-60)	1285.5	1639.1	1349.1
Transition Zone (100-110 cm)	9002.3	14197.9	10506.9
Sludge Zone (>110 cm)	28717.7	11672.5	33055.8

Taken from reference 25.

ASSESSMENT OF THE WCP-SITE FOR PHYTOREMEDIATION

Plant Growth Conditions

Successful implementation of phytoremediation technology depends on careful selection of plant species that are genetically capable of achieving the desired remediation goals, and that are also adapted for sustained growth under the climate and chemical conditions that prevail at the site. The climate, terrain and soil conditions at the Waukegan Manufactured Gas and Coke Plant site (WCP-site) all appear to be reasonable for plant growth and implementation of phytoremediation technology. In general, plants will have ample water for growth since the average annual rainfall is 33 inches and is scattered throughout the year. Warm temperatures in the summer and moderate temperatures during the winter will enhance plant growth and encourage microbial activity in the soil. The fertility of the soil is marginal, but is within the bounds of many natural soils that support native vegetation. The level of remaining organic pollutants and heavy metals are below concentrations known to kill plants. Thus the conditions present at the WCP-site are favorable for plant growth and use of phytoremediation technology.

Topography

The flat nature of the site and easy access from several different sides will make it easy to plant vegetation, monitor its growth, and exercise management practices as necessary. The flat nature of the site might be detrimental to plant growth if it caused water to stand and thereby kill plants by cutting off oxygen to their roots. However, there is no history of standing water at this site.

Available Water

Plants will have ample water for growth since the annual precipitation for the area is 33 inches and the water table across the site is approximately 4.5 to 5 feet deep. During the wet portions of the growing season plants will draw heavily from water in the upper portions

of the soil. As the surface moisture is removed during the course of the summer, plants will draw moisture from deeper zones and eventually reach the steady water supply available at the water table.

It is estimated that a well established and maintained tallgrass prairie at the WCP-site will return greater than 90% of the annual precipitation to the atmosphere via evapotranspiration. This estimate is based on lysimeter studies conducted at the U.S. Dept. of Agriculture Station in east-central Ohio near Coshocton (26) that showed that an established 6 year-old cover of mixed brome grass and alfalfa evapotranspired between 96 and 100% of the annual precipitation during 3 consecutive years (Table 3). It is presumed that after 6 years this brome grass-alfalfa pasture had reverted primarily to brome grass since it is normal for a stand of alfalfa to be replaced over time by competing species. In this event the high evapotranspiration rates shown in Table 3 reflect that of brome grass that characteristically grows to a maximum height of 3-4 feet, substantially less than that of the tallgrass prairie species to be planted at the WCP-site (ie. switchgrass, Figure 2).

Temperature

The length of the growing season in northern Illinois will be controlled primarily by temperature and to a lesser degree by day length for some species. For deciduous plants, growth will be restricted to the 5 to 6 month period extending from May to October when temperatures stay above freezing. This relatively short growing season is not ideal for those phytoremediation processes that depend on evapotranspiration. A favorable feature of tallgrass during the winter is that the abundant standing dead material (2-3 foot tall dead leaves) intercepts falling precipitation and serves as an evaporative surface (Figure 1), not a prominent feature of bare tree stems.

Table 2. Monthly summary of the accretion, depletion, and storage of soil water as determined by the weighing monolith lysimeter Y101D at the U.S. Department of Agriculture Experimental Station located near Coshocton, Ohio.

Year, month, and crop grown	Accretion			Depletion				Storage in 8-foot profile	
	Precipitation	Condensation	Total	Runoff	Evapotranspiration	Percolation	Total	Net increase	Net decrease
1953—Brome-alfalfa:	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>		
January.....	5.60	¹ 1.14	6.74	0	¹ 1.60	0	1.60	5.14	-----
February.....	1.45	¹ 1.41	2.86	0	¹ 2.11	0	2.11	.75	-----
March.....	3.54	¹ 1.26	4.80	0	¹ 2.54	.22	2.76	2.04	-----
April.....	2.71	1.00	3.71	0	3.30	.74	4.04	-----	0.33
May.....	4.22	.63	4.85	.01	6.23	.54	6.78	-----	1.93
June.....	2.36	.47	2.83	.02	6.08	.03	6.13	-----	3.30
July.....	4.20	.34	4.54	0	6.16	0	6.16	-----	1.62
August.....	1.01	.54	1.55	0	4.62	0	4.62	-----	3.07
September.....	1.12	.65	1.77	0	4.19	0	4.19	-----	2.42
October.....	.57	.65	1.22	0	2.08	0	2.08	-----	.86
November.....	1.33	¹ 1.36	2.69	0	¹ 1.88	0	1.88	.81	-----
December.....	2.56	¹ 1.36	3.92	0	¹ 1.92	0	1.92	2.00	-----
Total.....	30.67	10.81	41.48	.03	42.71	1.53	44.27	10.74	13.53
Percentage of total accretion or depletion.....	<i>Percent</i> 73.94	<i>Percent</i> 26.06	<i>Percent</i> 100.00	<i>Percent</i> .06	<i>Percent</i> 96.48	<i>Percent</i> 3.46	<i>Percent</i> 100.00		
1954—Brome-alfalfa:	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>
January.....	2.82	¹ 1.42	4.24	0.01	¹ 1.89	0	1.90	2.34	-----
February.....	2.21	¹ 1.34	3.55	0	¹ 2.23	0	2.23	1.32	-----
March.....	4.77	¹ 2.04	6.81	0	¹ 4.08	0	4.08	2.73	-----
April.....	3.29	1.04	4.33	0	4.65	0	4.65	-----	0.32
May.....	2.44	.78	3.22	0	6.16	0	6.16	-----	2.94
June.....	2.21	.71	2.92	.01	5.19	0	5.20	-----	2.28
July.....	3.39	.67	4.06	0	5.85	0	5.85	-----	1.79
August.....	3.57	.76	4.33	0	4.80	0	4.80	-----	.47
September.....	1.42	1.02	2.44	0	3.79	0	3.79	-----	1.35
October.....	6.24	1.01	7.25	0	2.88	0	2.88	4.37	-----
November.....	1.55	¹ 1.28	2.83	0	¹ 2.12	0	2.12	.71	-----
December.....	2.77	¹ 1.50	4.27	0	¹ 1.92	0	1.92	2.35	-----
Total.....	36.68	13.57	50.25	.02	45.56	0	45.58	13.82	9.15
Percentage of total accretion or depletion.....	<i>Percent</i> 73.00	<i>Percent</i> 27.00	<i>Percent</i> 100.00	<i>Percent</i> .04	<i>Percent</i> 99.96	<i>Percent</i> 0	<i>Percent</i> 100.00		
1955—Brome-alfalfa:	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>		
January.....	1.82	¹ 1.59	3.41	0	¹ 2.26	0	2.26	1.15	-----
February.....	3.57	¹ 1.24	4.81	.17	¹ 2.10	.12	2.39	2.42	-----
March.....	5.07	¹ 1.93	7.00	0	¹ 3.97	1.05	5.02	1.98	-----
April.....	3.89	.99	4.88	.01	5.24	.44	5.69	-----	0.81
May.....	1.70	.57	2.27	0	6.79	.09	6.88	-----	4.61
June.....	² 6.74	.76	² 7.50	0	5.56	0	5.56	1.94	-----
July.....	3.82	.60	4.42	0	6.86	0	6.86	-----	2.44
August.....	3.66	.76	4.42	0	5.36	0	5.36	-----	.94
September.....	2.45	.94	3.39	0	4.07	0	4.07	-----	.68
October.....	2.40	1.06	3.46	0	3.09	0	3.09	.37	-----
November.....	¹ 3.54	¹ 1.23	4.77	0	¹ 2.00	0	2.00	2.77	-----
December.....	.35	¹ 1.67	2.02	0	¹ 2.04	0	2.04	-----	.02
Total.....	39.01	13.34	52.35	.18	¹ 49.34	1.70	51.22	10.63	9.50
Percentage of total accretion or depletion.....	<i>Percent</i> 74.52	<i>Percent</i> 25.48	<i>Percent</i> 100.00	<i>Percent</i> .35	<i>Percent</i> 96.33	<i>Percent</i> 3.32	<i>Percent</i> 100.00		

¹ Some snowfall during the month; some values may be too high because of drifting of snow.

² Includes irrigation of 3.61 inches.

Taken from reference 26.

Soil

Nutrients: Sandy soils as prevail at the WCP-site are generally deficient in inorganic nutrients (ie. nitrogen, phosphorous, and potassium) necessary for plant growth. Low soil nutrients are known to restrict the growth and yield of shallow rooted agricultural crop plants, but this is not necessarily true for native plants used in phytoremediation. Many deep rooted, native species are adapted to survive and grow on low nutrient soils through their ability to explore large volumes of soil by developing extensive, deep root systems. Thus, for many plant species the depth and breadth of the plant's root system is inversely proportional to the availability of nutrients. Thus, low amounts of nutrients at the WCP-site favor the growth of deep roots once certain species are established. Nutrient analyses of selected regions of the WCP-site should be conducted to gain further insight into how the site should be managed.

pH: Extreme pH values lying outside the broad range of 5.5 to 8.5 will dramatically restrict the growth of many plant species. This deterrent to plant growth can be alleviated through soil additives. Regions of the WCP-site where there is either sparse or no vegetation growing should be analyzed for pH values at different soil depths.

Salt: High salt content in soils inhibits plant growth by preventing normal water uptake. It is unlikely that this condition prevails at the WCP-site, but it would be advisable to confirm this contention by conducting a limited number of total salt analyses on samples taken from bare or sparsely vegetated regions of the site.

Compaction: Historical records indicate that portions of the WCP-site have been subjected to the heavy weight of earth moving equipment, stored overburden materials, and other procedures that create hard, impermeable soil. The entire site should be examined for such areas and appropriate steps taken to alleviate this condition so that plant roots can grow and penetrate lower soil zones.

Toxins: There are two known toxins, PAHs and arsenic, existing at the site whose phytotoxic properties need to be considered. Both laboratory studies and field analyses indicate that low levels of PAHs are not toxic to plants (10). Extremely high levels of PAHs may be toxic to some plant species, but there are plant species (ie. mulberry) that are known to grow in soil heavily contaminated with PAHs. Arsenic is of greater concern because reasonably low levels (200 ppm) are known to inhibit the growth but not necessarily kill many plant species (27). However, there are also numerous reports of plant species that tolerate levels of arsenic as high as 42,000 ppm (28,29). Thus the correct choice of plants to be grown at this site becomes a critical issue in achieving successful phytoremediation. In this regard, careful attention should be given to what is currently growing at the site.

Vegetation Currently Growing At The WCP-Site

Analysis of the site regarding the kind, distribution, and health of existing, volunteer vegetation is extremely informative in planning a successful phytoremediation strategy. Although the initial vegetation analysis at the site was conducted during January when plants were dormant and there was a partial snow cover, several important and conclusive observations were made. First, both tree and grass species are growing at the site indicating a natural tendency for a savannah type community of plants to revegetate the site. This observation is consistent with the known ecology of this region of Illinois (Figure 9). Secondly vegetation has successfully invaded and established itself by natural means across the entire site with the exception of a few zones where standing, dormant and/or dead material were not observed to protrude above the snow cover. These zones need to be examined more closely during the growing season. The third important observation is that two deep-rooted prairie grasses (little bluestem and switchgrass) that have been reported to stimulate the degradation of PAHs in laboratory experiments (22) are growing at the site. Certain cultivars

of little bluestem are also tolerant to high levels of arsenic exposure (28). These same two species are the most prominent grasses present in pristine prairies located 4 miles north of the site in Illinois Beach State Park.

PHYTOREMEDIATION OF THE VADOSE ZONE AT THE WCP-SITE

Method

Site preparation: Those portions of the site where the soil has been compacted or covered with a hard crust of parking gravel will be loosened by plowing. Stockpiled soil may be used in part to fill in excavated areas where heavily contaminated material has been removed. Ideally, during relocation of stockpiled soil it should be positioned approximately 6" to 18" beneath the soil surface where oxygen dependent plant-microbial degradation will be very active.

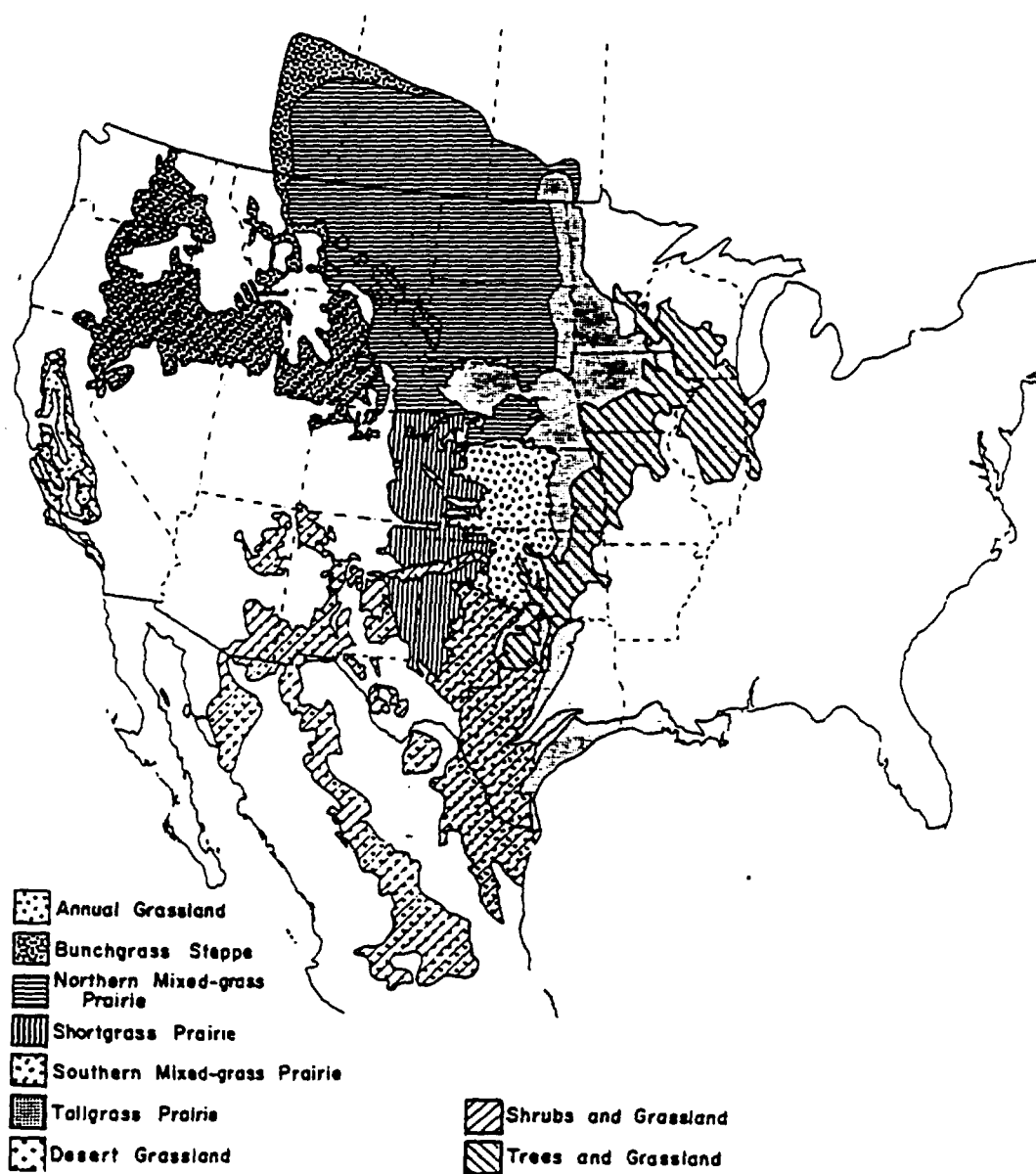
During the removal of heavily contaminated material and relocation of stockpiled soil care should be taken when possible to preserve the existing patches of prairie grass growing at the site. The disturbed areas must be graded, tilled, and allowed to settle; thereby providing a smooth, firm planting surface. Fertilizer should also be provided during seedbed preparation if soil analysis results warrant its addition.

Planting: The entire area will be seeded with a mixture of four tallgrass species.

The species will be: little bluestem (Schizachyrium scoparius), big bluestem (Andropogon gerardi), Indiangrass (Sorghastrum nutans), and switchgrass (Panicum virgatum). Areas with high concentrations and/or deep deposits of PAHs will also be planted with mulberry saplings on 15-foot centers.

Monitoring and maintenance: During the first year the germination, survival, growth rate, plant size, and leaf color will be monitored on a biweekly basis. Replanting and fertilization will be done as needed to achieve a solid cover.

Figure 9. Distribution of major grassland types in the United States.



Taken from reference 31.

Rational for using selected plants

Prairie Grasses

1. native to northern Illinois (Figure 9)
2. two of the grasses (switchgrass and little bluestem) are currently growing on the site
3. genetically capable of developing deep, large roots (roots can be 6 feet deep and account for 80% of the plant's total biomass) (30,31)
4. perennial grasses
5. will grow in sandy, nutrient poor soil
6. grow fast
7. high rate of evapotranspiration (30)
8. their root systems have been reported to foster the degradation of PAHs (22,23,24)

Mulberry

1. native to northern Illinois
2. genetically capable of developing finely dispersed, 10 foot deep roots (30)
3. perennial
4. will grow in sandy, nutrient poor soil
5. grows fast
6. high rate of evapotranspiration
7. know to grow at PAH contaminated sites
8. produces flavonoid compounds that serve as a natural substrate for bacteria capable of degrading polyaromatic compounds (18,19)
9. enhances aeration of the soil through rapid root turnover

Anticipated results

Erosion: After the first growing season the entire site will be covered by a dense stand of grass and no erosion will occur.

Leaching: The amount of soluble compounds that are leached from the vadose zone to the groundwater will be steadily reduced through the removal of soil water via plant evapotranspiration and the binding of materials to newly synthesized organic matter arising from root turnover (continuous growth and death of roots). The influence of these processes is proportional to the biomass of both shoot and root material. It is estimated that these processes will reach their maximum after 3 years when maximum rates of above and below ground

biomass production will be realized. The mulberry trees will grow more slowly and reach their maximum potential to arrest leaching after 10 to 15 years.

PAH degradation: As the root systems of both the grass species and mulberry develop they will explore the entire vadose zone. Associated with this growth and development is the continuous turnover of fine roots (roots 1 mm in diameter or less). This turnover stimulates microbial growth by enhancing soil aeration and providing microbial substrates. The continuous random growth of new fine roots ensures that over time all portions of the soil in the root zone are visited by roots. Thus, it is not necessary for the water insoluble PAHs to move to the roots; the roots and associated microbes move to the immobile PAHs. This is a slow process, but the gradual degradation of this class of recalcitrant pollutants will occur continuously; therefore, after 15 to 20 year period insignificant amounts of the PAHs will remain.

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